

# *Intensive Dryland Agriculture in Kaupō, Maui, Hawaiian Islands*



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## INTRODUCTION: DRYLAND FIELD SYSTEMS IN HAWAI‘I

ANTHROPOLOGISTS HAVE LONG RECOGNIZED THAT within the broader sphere of Oceanic societies, Hawai‘i reached an apogee of sociopolitical complexity (Goldman 1970; Sahlins 1958, 1972). Regardless of whether one classifies late pre-Contact Hawaiian polities as highly elaborated chiefdoms (Earle 1997) or as emergent archaic states (Hommon 1986; Kirch 2005, 2007), there is general agreement that a series of social, political, and ideological transformations set Hawai‘i apart from other Polynesian societies. In an effort to track the emergence of sociopolitical complexity in the late period prior to contact with the West, the economic foundations underlying these transformations are of particular interest to archaeologists.

At the time of initial contact, Hawaiian subsistence economy was dominated by two distinct agro-ecosystems (Kirch 1994; Ladefoged et al. 2009; Vitousek et al. 2004). Pondfield irrigation dominated the geologically older landscapes (from West Maui to Kaua‘i) with significant valley incision and permanent streams that could feed irrigation canals. These pondfields supported a monoculture of taro (*Colocasia esculenta*). The geologically younger islands (notably East Maui and Hawai‘i) had only small areas with irrigation, but boasted extensive tracts of dryland, rainfed intensive cultivation. These dryland systems were focused on sweet potato (*Ipomoea batatas*), augmented by dryland taro, yams (*Dioscorea* spp.), and sugarcane (*Saccharum officinarum*). In opposition to the Wittfogelian model of the primacy of irrigation in early state formation, Kirch (1994:251–268) showed that the Hawaiian dryland systems were associated with the most aggressive, expansionistic polities led by Kalani‘ōpu‘u (Hawai‘i Is.) and Kahekili (Maui Is.) at the time of Captain James Cook’s arrival in the eastern end of the archipelago, in 1778–1779. Indeed, a critical tension between the dryland and irrigated agro-ecosystems that respectively dominated the eastern and western

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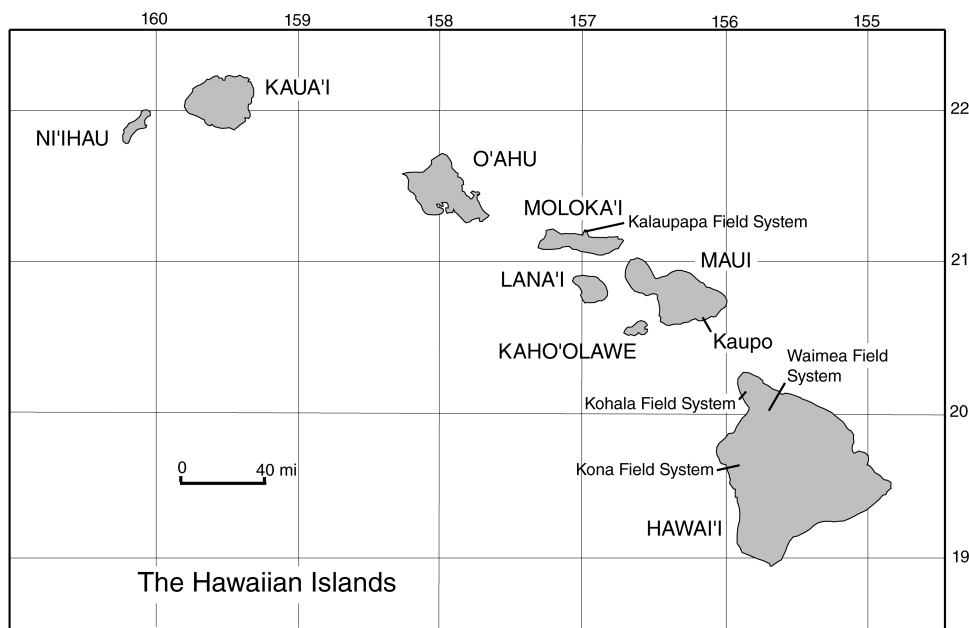


Fig. 1. Map of the Hawaiian Islands, showing the location of Kaupō and of major dryland field systems.

sectors of this large archipelago played a key role in the political dynamics of late prehistoric and early post-Contact Hawai'i (Kirch 2005, 2007).

Although Hawaiian irrigated landscapes persisted throughout the historic period (Handy 1940; Handy and Handy 1972), the intensive dryland field systems were abandoned in the early decades of the nineteenth century. This rapid "dis-intensification" (to use Brookfield's [1972] term) of the dryland systems was a consequence of demographic collapse, exacerbated by significantly greater labor inputs required for the maintenance of the dryland systems. Only with the advent of settlement-pattern archaeology in the late 1960s and early 1970s did the former extent and significance of the Hawaiian dryland field systems become apparent.

Four field systems have now been archaeologically investigated, three on Hawai'i and one on Moloka'i (Fig. 1): (1) The Kohala Field System of the northern peninsula of Hawai'i Island covers c. 60 km<sup>2</sup> in a continuous reticulate grid of closely spaced field walls or bunds, crosscut by trails that served as territorial boundaries (Ladefoged et al. 1996, 2003; Newman n.d.; Rosendahl 1972, 1994). Recent radiocarbon dating reveals that this system was established around A.D. 1400, and underwent a distinct phase of intensification after about A.D. 1650 (Ladefoged and Graves 2008). (2) Less well preserved and not as intensively studied, the Kona Field System lying across the leeward flanks of Hualālai and Mauna Loa volcanoes may have extended over as much as 137 km<sup>2</sup> (Allen 2001; Schilt 1984). This system is also defined by an impressive gridwork of field walls and terraces, although here the main walls run up- and downslope. (3) The Waimea Field System (Burtchard and Tomonari-Tuggle 2004; Clark and Kirch 1983)

has had the least amount of investigation, but is similar in its morphology to that of Kohala.<sup>1</sup> (4) On Moloka'i Island, an intensive dryland field system with another grid pattern of closely spaced field walls covers the Kalaupapa Peninsula, an area of late-stage rejuvenation volcanism (Kirch 2002; McCoy 2005, 2006). All of these dryland field systems depended on a critical combination of two key environmental parameters: their location on young geological substrates (<400 kyr age), combined with annual rainfall regimes sufficient to support sweet potato (>750 mm), but not so excessive as to have leached critical nutrients from the soil (Kirch et al. 2004; Vitousek et al. 2004).

Eastern Maui, a massive shield volcano presided over by the 3,055-meter high crater of Haleakalā, offers a similar mix of young, undissected volcanic substrates combined with suitable seasonal rainfall. Recent geographic information system (GIS) modeling of the environmental parameters suitable for intensive dryland agriculture in Hawai'i predicts the former presence of intensive dryland field systems on parts of Maui (Ladefoged et al. 2009). Ethnographer E.S.C. Handy, who spent brief periods on Maui during his archipelago-wide survey of "traditional" Hawaiian agricultural practices in the 1930s, referred to the leeward districts from Kaupō through Kahikinui and Honua'ula, to Kula as "the greatest continuous dry planting area in the Hawaiian islands" (1940:161). The importance of Kahikinui as a dryland agricultural zone has been documented in archaeological studies over the past decade (Coil and Kirch 2005; Dixon et al. 1999; Kirch 1997). However, Kahikinui lacks true field systems in sense of continuous reticulate grids of fields and boundaries, as seen in the Kohala, Kona, Waimea, or Kalaupapa systems. Rather, the Kahikinui pattern was adapted to the highly variegated mosaic of *kīpuka* (older substrate patches) and swales in this young 'a'a lava landscape (Coil and Kirch 2005).

Kaupō district on the southeastern flank of Haleakalā offers an ideal combination of substrate age and rainfall, a predictable environment for an intensive dryland field system. In 2006, examination of high-resolution color aerial photographs of Kaupō revealed the presence of reticulate grid patterns over significant parts of the landscape, potentially confirming the existence of a major Hawaiian dryland field system, the first to be identified for Maui Island. Here we present the results of recent research combining remote sensing and GIS analysis with on-the-ground field survey. These results document the former presence of a major field system in Kaupō, one which ethnohistoric sources suggest provided key economic support to the regime of the protohistoric Maui king Kekaulike and his successors. This adds appreciably to our knowledge of the distribution of Hawaiian dryland agro-ecosystems, and to their significance in the rise of archaic states in Hawai'i during the final centuries prior to European contact (Kirch 2005).

#### THE KAUPŌ DISTRICT

Kaupō was one of 12 ancient districts (*moku*) into which Maui Island was politically subdivided. Geographically, Kaupō is bounded on the west by Wai'ōpai Gulch and on the east by Kālepa Gulch, a linear distance of about 13 km. The *moku* incorporated the vast sweep up the slopes to Haleakalā to the peak at Pōhaku Pālaha (2470 m elevation). The district is dominated by "Kaupō Gap,"

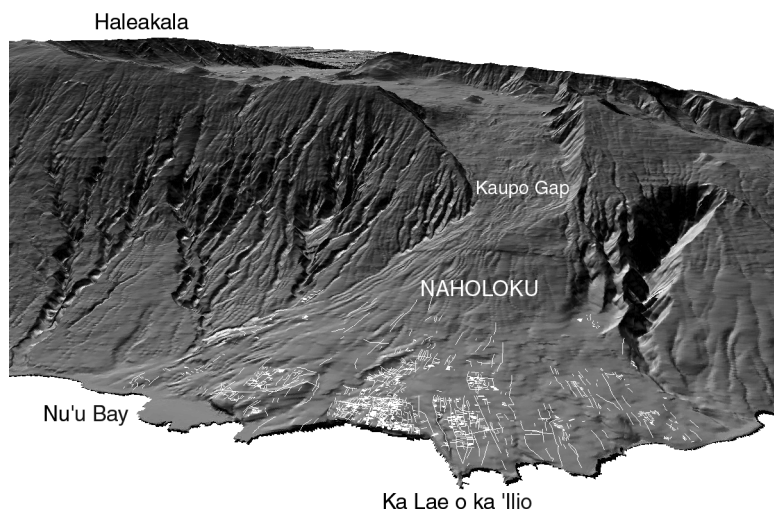


Fig. 2. Oblique digital elevation model of the Kaupō region as viewed from the southeast, showing the Nāholokū fan of young lava flows emanating out from Haleakalā Crater via Kaupō Gap. The Haleakalā summit attains a maximum elevation of 3055 m above sea level.

originally an erosional valley of Pleistocene age incised deeply into the Haleakalā shield so as to breach the southern wall of Haleakalā Crater (Fig. 2). Beginning c. 120 kyr ago, a rejuvenation phase of volcanism (the Hana Volcanics; Stearns and MacDonald 1942) led to a massive outpouring of lava flows (and one major mudflow) through the Kaupō Gap and down to the sea, creating a vast accretion fan (Fig. 3). The Hawaiians called this fan Nāholokū, “The Cloak,” an apt metaphor. It was this great fan of young lavas with high nutrient content, combined with ideal climate conditions that provided the environmental potential for intensive agricultural production in Kaupō.

In the traditional Hawaiian land system, the *moku* of Kaupō was subdivided into a hierarchy of territorial segments, *ahupua'a*, which in turn incorporated smaller subdivisions progressively termed *'ili*, *mo'o*, and *paukū*. At least 18 territorial names are recorded for Kaupō (see Sterling 1998:166 map), but which were *ahupua'a* and which were *'ili* (subsections of an *ahupua'a*) is uncertain. It seems likely that Nāholokū may have been a single large *ahupua'a* partitioned into as many as 10 *'ili*, incorporating the core of the dryland field system. Nu'u and Nākula are large *ahupua'a* lying to the west of the intensive field system, encompassing less productive and drier lands.

Handy wrote that “Kaupo has been famous for its sweet potatoes, both in ancient times and in recent years,” but lamented that “this old culture is unfortunately vanishing here, due to a combination of economic and climatic circumstances” (1940:161). He reported that sweet potatoes were cultivated from sea level up to about 2,000 feet elevation. Handy also claims that “formerly great quantities of dry taro were planted in the lower forest belt from one end of the district to the other” (1940:113; see also Handy and Handy 1972:507–508). Handy's brief description suggests an altitudinal zonation of agriculture, with





Fig. 3. View of the Nāholokū fan and Kaupō Gap, taken from the Paukū area of the dryland field system.

sweet potatoes dominating the lower slopes and dryland taro becoming increasingly important inland on the forested slopes.

Kaupō has received very little archaeological research. Winslow Walker (1930) conducted a reconnaissance survey in 1928–1929, concentrating on temple ruins, of which he reported twenty-four. Selections from Walker's unpublished manuscript were incorporated into Sterling's *Sites of Maui* (1998). Soehren (1963) also drew on Walker's survey, adding a few new sites, but his coverage was hardly systematic. In 2003 Kirch and Holson began a long-term archaeological survey of the *ahupua'a* of Nu'u, on the western edge of the Kaupō fan; to date more than 350 sites have been recorded in a GIS database. For the remainder of Kaupō district, however, we are unaware of any modern archaeological surveys.

#### KAUPŌ AS AN AGRICULTURAL ENVIRONMENT

Ladefoged et al. (2009) use GIS to model the optimal zones for intensive dryland sweet potato cultivation in Hawai'i, combining rainfall, elevation, and substrate age. Together, these three variables determine the overall availability of key plant nutrients, which can be measured as "base saturation" (Vitousek 2004). In general, younger geological substrates have higher base saturation, but extremely young substrates (e.g., 'a'a lava flows younger than about 10 kyr) may not have had sufficient time to accumulate the fine-grained aeolian sediment necessary as a planting medium for root crops. Old substrates, in contrast, have had base saturation depleted through weathering and leaching. The key variable is amount of rainfall; if annual rainfall is high, then nutrient depletion proceeds more rapidly.

Substrate age must therefore be correlated with rainfall to determine the level of base saturation and nutrient availability. Elevation, the third variable to be considered, is important both because rainfall and elevation are strongly correlated on volcanic islands with orographic precipitation, and because elevation also correlates with temperature. Sweet potatoes are reasonably tolerant of cold temperatures, but “grow best where the average temperature is 75 °F [23.9 °C] or more with a well-distributed annual rainfall of 30–50 in. [762–1270 mm] and an abundance of sunshine” (Purseglove 1968:82). On average, there is a drop in temperature of 6.5 °C/1000 m elevation in Hawai‘i (Giambelluca and Schroeder 1998:49). Since average temperatures at sea level in Hawai‘i range from about 23–35 °C, the optimal elevation zone for sweet potato cultivation—in terms of temperature alone—would be from sea level up to about 500 m elevation.

As noted earlier, the Nāholokū fan dominating Kaupō consists of a massive outpouring of lavas from the post-shield building phase of Haleakalā Volcano known as the Hana Volcanic Series (Sherrod et al. 2007; Stearns and MacDonald 1942). These Hana lavas overlie the older Kula Volcanic Series land surfaces, which persist on the eastern and especially western margins of Kaupō District. The relatively young geologic age of the Hana Volcanic Series (<140 kyr) makes them particularly suited for intensive cultivation because the lack of leaching gives them higher base saturation and nutrient status relative to the older Kula Volcanic Series surfaces (>140 kyr).

There is nonetheless considerable variation in the age and character of individual flows making up the Nāholokū fan, whose surfaces would have been subject to Hawaiian cultivation. Detailed mapping by the U.S. Geological Survey (Sherrod et al. 2007) has defined individual flow boundaries and ages. Much of the western part of the Nāholokū fan is covered by two massive ‘a‘a flows, the Pu‘u Maile Basanite (3–5 kyr) and the Pu‘u Nole Basanite (0.75–1 kyr). Being only a few thousand years old, these have little if any fine sediment capping their stony surfaces, and hence were of limited use for cultivation. On the eastern edge of the Nāholokū fan, the Loaloa basanite flow (5–13 kyr) and the Kaupo Basanite (13–30 kyr) are sufficiently old to have reasonably well-developed soils with high nutrient levels. The two substrates of greatest agricultural potential are found in the central part of the fan: the Mamalu Bay Basanite and the Kamanawa Bay Basanite (both 50–140 kyr). These flows are sufficiently old to have a substantial depth of fine aeolian sediment yet not too old to be nutrient deprived.

Rainfall declines significantly along a gradient from northeast to southwest across the Kaupō fan, a consequence of the rain shadow created by Haleakalā Mountain (Giambelluca and Schroeder 1998:56; Giambelluca et al. 1986:Fig. A.79). As a result, on the eastern side of the Nāholokū fan at 900 m elevation, annual rainfall totals 2000 mm. By Nu‘u Bay, on the southwestern edge, however, this declines to approximately 800 mm. Thus the entire Nāholokū fan falls within the suitable range for sweet potato cultivation, although the more easterly and higher elevations may have been less productive due to an excess of rainfall and lower temperatures. The most optimal part of the fan for growing sweet potatoes would be the central area below about 300 m elevation, with annual rainfall between about 1000–1500 mm. The slightly higher elevations, with greater precipitation, would have been suited to dryland taro cultivation, as Handy’s observations (1940:113) suggested.

Seasonal variation in rainfall is also critical. Most of the annual rainfall over the Nāholokū fan falls during the period between November and April. A cropping system based on sweet potatoes would be best adapted to such a seasonal climate regime. Handy (1940:143) notes that Hawaiian varieties of sweet potato had growing seasons ranging from three to six months. Dryland taro requires longer maturation times, but taro would presumably be concentrated in the higher elevations where overall rainfall was higher and the effects of seasonality partly mitigated by afternoon and evening fog-drip precipitation (see Stock et al. 2003).

In short, the particular combination of substrate age, rainfall, and elevation across the Nāholokū fan offered a near optimal region for intensive dryland cultivation. Nonetheless, there is some spatial variation over the surface of the Nāholokū fan reflecting differences in substrate ages and the rainfall gradient. The best combination of environmental parameters lies in the central part of the Nāholokū fan, below 300 m elevation, where the older Hana lava flows have deep soils yet still sufficiently high base saturation, and where rainfall averages around 1000 mm. Much of the eastern part of the fan was also suitable to cultivation, although substrates are somewhat younger. Significant parts of the fan on the west, however, would have been of limited agricultural potential, due to their very young substrate ages and more marginal rainfall regimes.

#### REMOTE SENSING AND GIS ANALYSIS OF THE KAUPŌ FIELD SYSTEM

The first stage in our research was a district-wide spatial analysis of the Kaupō region using remote sensing and GIS, which allowed us to map archaeological features tentatively interpreted as deriving from intensive cultivation. The aerial photography analyzed in this study was obtained from the Pacific Disaster Center's (PDC) online archive of images (<http://www.pdc.org>). The images are ortho-rectified digitized versions of true color diapositive photographs obtained by the NOAA/NOS Benthic Habitat Mapping Program during March through July 2000 at a scale of 1:24,000, covering the lower elevation regions of the Hawaiian archipelago. The photographs were scanned by PDC at 800 dpi, which yields a ground resolution of approximately 0.85 m. Archaeological features are thus resolvable at sub-meter accuracy. In the photos, individual trees and shrubs, as well as freestanding walls, structures, and changes in vegetation patterns that correspond with subtle archaeological features are clearly visible.<sup>2</sup>

We analyzed the PDC images using ArcGIS 9.2, systematically examining the entire area within and buffering the Nāholokū fan for visual indications of artificial construction or landscape modification. As noted earlier, Hawaiian dryland field systems typically consisted of reticulate grids marked by low walls, embankments running along contours, and intersecting with trails or other walls running from the ocean to the uplands. Just such a combination of linear features is readily visible in the high-resolution PDC air photos for Kaupō. Two kinds of linear features were particularly prominent: (1) what appeared to be stone walls, marked by dark lines of rock and/or vegetation growing on rocks, running up- and down-slope and thus roughly north-south (N-S); and (2) more closely spaced dark lines running between and at right angles to the long N-S walls, hence in a roughly east-west (E-W) direction. We originally interpreted the E-W dark lines as rock walls, although as described further below, later ground-truthing showed these to

be vegetation growing selectively on underlying subtle stone-and-soil embankments. In ArcGIS, both kinds of linear features were traced into separate data layers, thus creating an overlay with all visible indications of the putative dryland field system. In addition, we were able to discern numerous discrete stone structures, including what appeared to be enclosures, platforms, and irregularly shaped structures. These were similarly digitized in a separate data layer. Finally, we noted substantial areas with concentrations of small (c. 5–7 m diameter) dot-like features, which we suspected were bulldozer push-piles in areas that had undergone “grubbing”—the mechanical clearance of stones for pasture improvement—by Kaupō Ranch.<sup>3</sup>

As with any landscape, Kaupō is a palimpsest, and not all features delineated by GIS analysis are of the same age. Most of the features identified in our GIS analysis can probably be attributed to traditional Hawaiian land use practices. However, since the late nineteenth century, Kaupō has been used for cattle ranching, and some of the longer N-S alignments (and perhaps some E-W alignments) seen on the aerial photos may be stone walls built to control cattle. In some cases such cattle walls may have been constructed upon older features. It is also likely that some portion of the freestanding stone structures identified on the aerial photos date to the post-Contact period; only ground-truthing and excavation will ultimately confirm this.

Figure 4 shows the distribution and density of linear features over the Nāho-

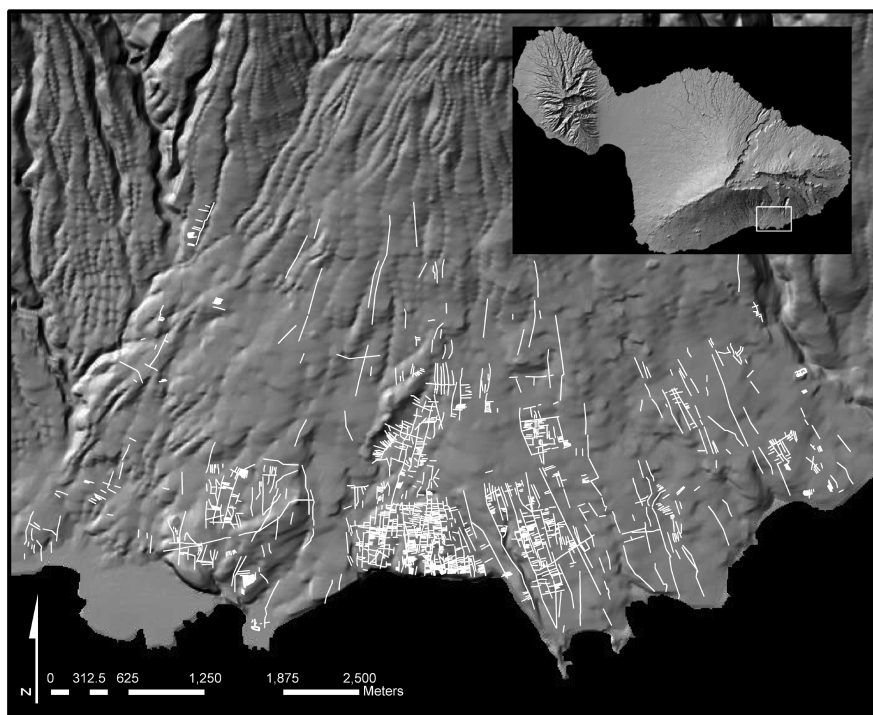


Fig. 4. GIS map of linear features derived from aerial photo interpretation, most of which probably represent agricultural field system walls and embankments.

lokū fan; clearly, some areas contain dense collections of walls while other areas have few or no traces. The general trend shows a much higher density of features within 1.5 km of the coast, with the majority of walls further inland running from the ocean up-slope and likely representing territorial boundaries. Within the lower coastal zone, however, there are several distinctly barren patches. The lack of features within these areas is likely based on two different causal factors: modern land use practices and soil fertility limitations.

The aerial photo analysis indicates that significant portions of the Nāholokū fan have been affected by modern land use activities, especially “grubbing.” In some areas, the pattern of terraces and walls appeared to be completely intact and we could also discern what appeared to be individual archaeological features such as enclosures or platforms. In other areas, the terraces and boundary walls were only visible as faint “shadows”; it was in these areas that hundreds of small “dots” were visible, representing piles of bulldozer push. Such modern disturbance, however, has not entirely erased traces of the earlier field system, which can still often be made out as faint “ghosts” of linear alignments. Nonetheless, such modern land grubbing makes aerial photo interpretation more problematic for about 4 km<sup>2</sup> of the Nāholokū fan.

Other areas that have a low density or absence of linear features cannot be attributed to mechanical earthmoving, but apparently reflect a true absence of agricultural features. As will be discussed below, these “empty” areas are concentrated on geological substrates with low potential for cultivation. Figure 5 plots

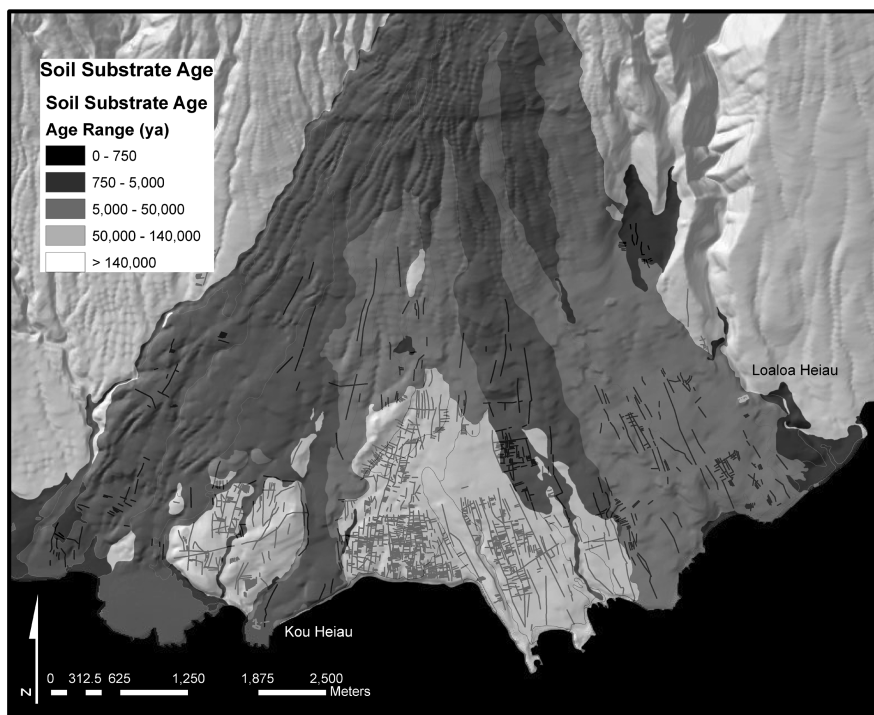


Fig. 5. The distribution of field system features in relation to geological substrate age. Note the high concentration of linear features on substrates in the 50–140 kyr age range.

the distribution of linear features in relation to five classes of substrate age. The highest concentration of such features is in the central part of the Nāholokū fan, on substrates of the Mamalu Bay and Kamanawa Bay basanite flows, dating between 50–140 kyr in age. A significant number of linear features also appear on the Loaloa and Kaupō basanites on the eastern side of the fan, which range between 5–50 kyr in age, as well as on the Oili Pu‘u Basanite. In striking contrast, almost no features are discernable on the Pu‘u Nole Basanite, a massive ‘a‘a flow only 0.75–1 kyr old. We have field checked parts of this ‘a‘a flow in Nu‘u, and found that it completely lacks fine-grained soil particles on its jagged and rocky surface. This flow was probably of almost no value for cultivation. With the exception of the Pu‘u Nole substrate, most of the Nāholokū fan shows some traces of linear features that can tentatively be taken as indicative of intensive dryland cultivation.

Focusing on the central part of the Nāholokū fan, the N-S and E-W trending linear features display a non-random reticulate grid pattern that is marked by regularly spaced longer N-S alignments, with shorter, more closely spaced E-W alignments between them. Based on our knowledge of the four other Hawaiian field systems studied to date, the long N-S alignments most likely represent a sub-*ahupua‘a* level of territorial land divisions (either ‘*ili*’ or *mo‘o*), while the E-W lines define individual garden plots (*mo‘o* or *paukū*). The N-S alignments appear to be slightly wider and darker in the digitized imagery, suggesting that they incorporated a greater amount of stone. Many of the N-S alignments in the Paukū area run for 600–700 m, while those in the adjacent Puka‘auhuhu area are typically 1000–1200 m long. One alignment in Paukū can be traced inland for 1532 m. The spacing between these N-S walls is also quite consistent; a sample of 17 inter-wall distances measured along an E-W transect across the Paukū area gives a mean of  $50.4 \pm 14.1$  m (range 27.4 to 77.6 m). The shorter E-W linear features mostly run between single sets of N-S alignments, and thus appear to be subdivisions within a single long territorial unit. The spacing between these E-W walls, as measured along four different N-S transects (cross-cutting the E-W features) is also fairly consistent: the mean distance between these features ( $N = 81$ ) is  $11.7 \pm 4.8$  m (range 4.3 to 31.3 m). If, as seems evident, individual garden plots within the field system were defined by the intersections of N-S and E-W alignments, then an average sized plot had an area of about 580 m<sup>2</sup>, although some larger plots ranged between 1000–2,000 m<sup>2</sup>, while a few plots were as small as 250 m<sup>2</sup>.

The GIS analysis also allows us to calculate the approximate total area covered by intensive dryland farming in Kaupō. The Nāholokū fan covers approximately 25 km<sup>2</sup>, and at its widest breadth along the coast reaches a width of over 7 km. While the entire Nāholokū formation stretches nearly 5 km inland, only the lower 3 km below an elevation of about 400 m reveals evidence of landscape modification visible in the aerial photos. Archaeological survey in Kahikinui district suggests that dryland cultivation and land use extended as high as 600 m above sea level on leeward Maui. It is likely that heavy vegetation cover on the higher slopes of the Nāholokū fan is obscuring archaeological features; field survey will be necessary to determine this. The total area of the Nāholokū fan below 600 m is about 20 km<sup>2</sup>; however, removing areas of very young substrate that

seem not to have been utilized, we estimate the intensively cultivated portions of Nāholokū at between 12.5–15 km<sup>2</sup>.

#### 2007–2008 PEDESTRIAN SURVEY OF THE KAUPŌ FIELD SYSTEM

In October 2007, we followed up our GIS interpretation of the putative field system at Kaupō through intensive archaeological survey. As time was limited, and a complete reconnaissance of the entire Nāholokū fan was not possible, we decided to focus initial survey on the Paukū sector above Mamalu Bay. This area appeared from the aerial photos to be undisturbed by modern land use and alteration, and had the clearest grid pattern of reticulate N-S and E-W linear features. We spent several days carrying out intensive field survey within this Paukū area, concentrating on three sample “blocks” (see Fig. 6). Using a Trimble Geo-XM global positioning system (GPS) instrument, we traced linear features on the ground, thus verifying patterns that we had initially detected in our GIS analysis of the aerial photos. Within these sample blocks we also recorded all evident stone structures such as platforms, enclosures, and shelters, filling out standard survey forms for each structure.

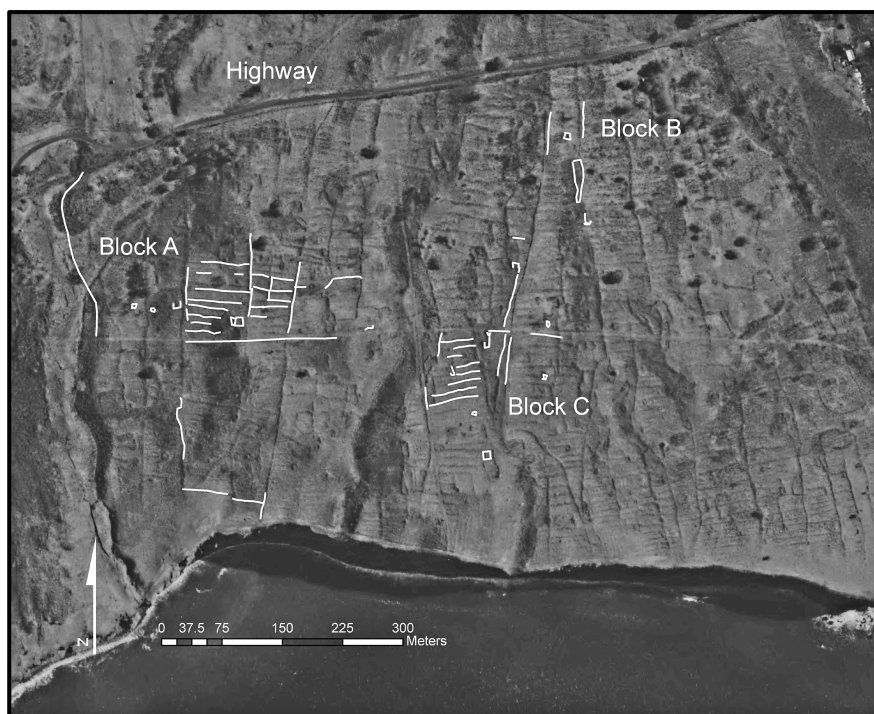


Fig. 6. Aerial photo of the Paukū area, with GPS ground-truthed features indicated. Note the high density of linear features visible. The N-S trending features are low stone walls, probably land divisions, while the numerous E-W features are low terrace embankments. See text for discussion of survey blocks.

In April 2008 we returned to Kaupō for a second phase of survey, this time concentrating on the *ahupua'a* of Nu'u, which spans the western edge of the Nāholokū fan and the margins of the field system as these were identified on the aerial photographs. We were especially interested in surveying two interfluvial ridges on the geologically older Kula Volcanic Series land surface where linear traces of putative field system terraces were faintly visible on the photographs. Since the Kaupō Field System appears to have targeted the younger Hana Series Volcanics, we were interested to determine whether the system did extend onto the older Kula substrate. As in the previous work, we used a Trimble Geo-XM GPS instrument to track field terraces on the ground, which could then be compared with the aerial photo analysis.

### *The Paukū Survey Area*

As indicated in Figure 6, the Paukū<sup>4</sup> survey area lies above Mamalu Bay and extends up to the circum-island road. (The word *paukū* in Hawaiian means “to section off,” and refers specifically to a land section smaller than a *mo'o*, that is, an individual garden plot [Pukui and Elbert 1986:320].) On the west, Paukū is bounded by the Pu'u Nole 'a'a flow extending into the sea at Lapehu Point; on the east it is defined by a long fence line descending to Ka Lae o ka 'Īlio Point and Kamanawa Bay. The pasture land to the east of his fence, in the land section of Puka'auhuhu appears to have been mechanically grubbed, although the “ghosts” of field walls can be made out on the aerial photos. The Paukū survey area itself, however, showed no signs of mechanical disturbance and, indeed, our field survey confirmed that it contains an extremely well-preserved example of intensive dryland field system.

Almost all of the Paukū survey area lies on the Mamalu Bay Basanite, providing an optimal combination of substrate age with rainfall, which is about 1000 mm in this area of Kaupō. A small part of the Paukū area near the coast lies on a substrate of Kaupō Mud Flow, a coarse conglomerate dating to 120–140 kyr (Sherrod et al. 2007). The land slopes gently from an elevation of 350 m at Kaupō Road (Route 31) down to the 75-m-high sea cliffs bounding Mamalu Bay. The topography is undulating, with low swales and ridges, reflecting its origin as an 'a'a lava flow. Vegetation cover consists primarily of a coarse, wide-bladed pasture grass (*Paspalum* sp. ?), interspersed with lantana (*Lantana camara*) and *koa hoale* (*Leucaena glauca*); all of these are alien species which have been naturalized in the Hawaiian lowlands. Fortunately, the Paukū area had been grazed by cattle shortly before our survey, reducing the pasture grass to stumpy clumps about 0.5 m high, and allowing for visibility of ground features between the clumps.

When we initially began walking transects through the Paukū area, we were surprised to find that the abundant E-W linear features that show so clearly on the PDC aerial photos, and which we thought would be substantial rock walls, were very difficult to identify on the ground. We soon realized, however, that the linear alignments visible in the aerial photos were actually rows of *koa hoale* shrubs (about 1–1.5 m high) growing preferentially along low earth-and-stone embankments or bunds. The embankments presumably provide a favorable edaphic environment for the *koa hoale*, probably due to enhanced water retention. Once we realized this association, it became relatively easy to locate the subtle



embankments, and to trace them with the Trimble GPS unit. In contrast to the low E-W embankments, the longer N-S trending features were more evident, consisting of wider and higher alignments incorporating a good deal of rock, and often becoming freestanding walls. We traced out both N-S and E-W linear features in three sample areas, designated Blocks A, B, and C, as shown in Figure 6. These correspond well with features traced using GIS from the PDC aerial photos, and confirmed that they were indeed part of an intensive dryland field system, as we had tentatively interpreted them.

The E-W trending embankments or bunds average 0.5–1 m wide, and rise between 15–30 cm above the adjacent ground level. They incorporate subangular basalt cobbles and occasional small boulders along with considerable amounts of gravel and earth, and were probably constructed from materials cleared from the field plots themselves. As noted earlier from our GIS analysis, the spacing between these embankments averages around 8–10 m, and the relatively clear ground between them constituted dryland planting terraces. We measured profiles across three sets of such terrace embankments, using a hand level and stadia rod; these are shown in Figure 7 (C–E). As can be seen, the embankments clearly define each terrace; degree of slope within terraces varies according to the local topography. Clearly, no attempt was made to level terraces as in irrigated pond-field systems, and we found no evidence of water control features or channels, leading us to conclude that the Paukū system was strictly rainfed.

We also closely examined several N-S trending alignments, and took two measured profiles across representative examples, shown in Figure 7 (A, B). These features not only run for much longer distances up- and downslope, but they are wider and higher than the terrace embankments. The N-S alignments are up to 5–6 m wide and typically 0.5 m high, and incorporate significant quantities of basalt cobbles and boulders. In some places the boulders are actually stacked 2–3 courses high, so that the alignment becomes a low freestanding wall. The function of these N-S features seems to be to define territorial units. They are most similar to the *kuaiwi* (“backbone”) stone alignments known from the Kona field system on Hawai‘i Island (Allen 2001). As far as we could determine, they are not trails as in the double-lined stone trails of the Kohala field system (Cordy and Kashko 1980), although trails or paths may well have run alongside the Paukū N-S features.

In addition to the reticulate grid formed by the intersection of the N-S alignments and E-W terrace embankments, the Paukū survey area contains numerous other stone structures, some 33 of which we recorded during our survey. Table 1 summarizes these structures by feature type and location within the survey blocks.

The most common feature type consists of stacked or core-filled stone-walled enclosures; many of these are rectangular and may be the foundation walls for thatched houses, but a few larger, irregular enclosures may be animal pens. One substantial enclosure in Block A, built up to a platform on the eastern side, may be a small agricultural shrine, as suggested by the presence of branch coral, a ritual offering. Seven platforms were recorded, typically rectangular or square in plan with sides averaging 3–4 m. Based on what we know of similar structures elsewhere in the islands, these are likely to be burial platforms of the early post-Contact period. The C-, U-, and L-shaped shelters, some of which adjoin small stone-faced terraces, are all likely to be habitation features, either permanent

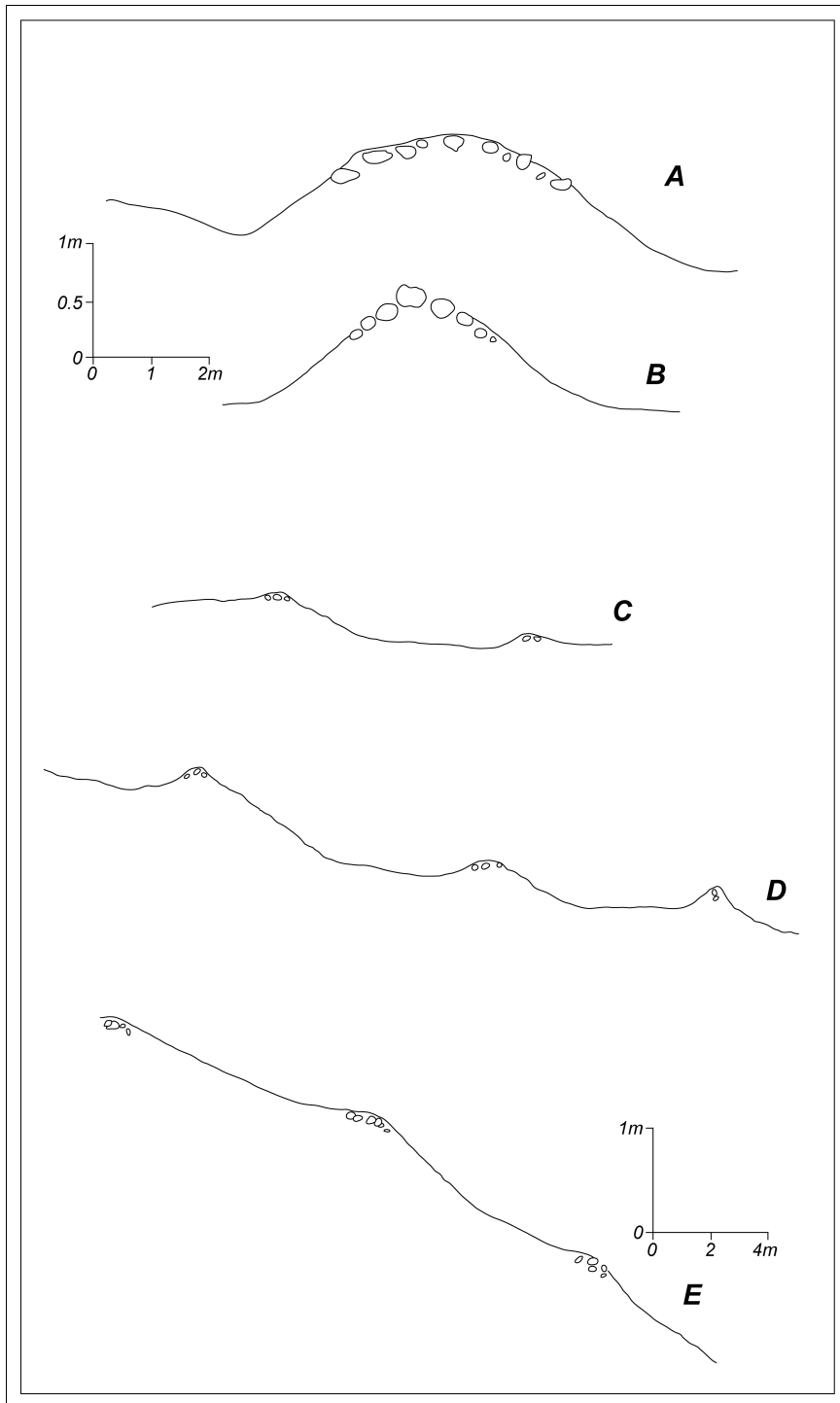


Fig. 7. Cross sections through representative N-S walls (A, B) and dryland terrace sets (C, D, E) in the Paukū survey area. A and B are shown at 2X vertical exaggeration, and C–E at 4X vertical exaggeration.

TABLE 1. DISTRIBUTION OF STONE STRUCTURES IN PAUKŪ SURVEY AREA.

FEATURE TYPE	BLOCK A	BLOCK B	BLOCK C	TOTAL
Enclosure	5	2	5	12
Platform	3		4	7
C- or U-shaped shelter	1		1	2
Linear or L-shaped shelter	2		3	5
Other	5		2	7

house sites or temporary field shelters within garden plots. In sum, the Paukū area consists not only of a dense grid of territorial boundaries and garden terrace embankments, but a settlement landscape also incorporating a range of residential, ritual, and special function features. In this regard it is very similar to other documented Hawaiian field systems.

### *The Nu‘u Survey Zone*

Whereas Paukū represents the dense core of the Kaupō field system, the *ahupua‘a* of Nu‘u straddles the western edge of the Nāholokū fan, at the margins of the zone considered ideal for intensive sweet potato cultivation. Most of the Nu‘u area is made up of two relatively young substrates: the Pu‘u Nole Basanite (0.75–1 kyr) which as already noted has almost no potential for cultivation, and the slightly older Pu‘u Maile Basanite (3–5 kyr). In previous archaeological survey, Kirch and Holson (unpublished data) have found numerous agricultural, residential, and ritual features on the Pu‘u Maile substrate, including field terraces across the bottoms of several swales. However, no formal field system grid as at Paukū had been observed.

The most westerly part of Nu‘u actually lies beyond the edge of the Nāholokū fan, and takes in a part of the much older Kula Volcanics land surface (>200 kyr). During our GIS analysis of the Kaupō district, we noted what appeared to be faint E–W linear alignments, much like those in the Paukū area, closely spaced on a prominent interfluvium of the Kula land surface between 300–400 m elevation (see Fig. 4). In April 2008 we were able to field survey this area in order to ground-truth the linear features detected on the aerial photos. Despite a fairly dense cover of meter-high grass, we were able to locate a succession of 20 low terrace embankments running across the Kula interfluvium, a higher number of features than could be detected on the aerial photos (the dense vegetation presumably obscures many features on the photos). These embankments were similar to the E–W embankments at Paukū, consisting again of basalt cobbles and a few boulders, but in this case without much gravel (probably reflecting the deeper weathering of this older land surface). We traced the embankment lines with GPS, and measurements taken along a transect descending across the features shows a fairly regular mean spacing of  $12.9 \pm 4.8$  m, again consistent with field widths within the main Kaupō field system. Several rectangular enclosures, including a possible ritual structure (*heiau*) were also recorded within this complex. On a second interfluvium to the west, overlooking Waoala Gulch, we were able to find only three terrace embankments.

Careful examination of the PDC aerial photos does not reveal any traces of linear features that might be field system terraces farther to the west of Nu'u and Waoala Gulch. We suspect that the rapid falloff in rainfall isohyets as one moves westward from Nu'u to Nākula *ahupua'a* may have discouraged any attempt to expand the field system in this direction. Nonetheless, it is interesting to note that at least a small section of older Kula land surface was put into intensive dryland cultivation, as evidenced by the terrace embankments recorded in our survey.

#### MAJOR TEMPLES ASSOCIATED WITH THE KAUPŌ FIELD SYSTEM

On Hawai'i Island, field system complexes are associated with prominent ceremonial structures (*heiau*) and royal residential centers, such as Mo'okini Heiau at the northern tip of Kohala, and the royal centers at Kealakekua and Hōnaunau in Kona. This strong association between field systems and ceremonial architecture is not surprising, given that these intensively cultivated field complexes provided the underpinning of the elite economy. As Valeri (1985) documents, the large temples functioned within the "state cults" of Lono (god of dryland agriculture) and Kū (god of war). Kaupō also fits this pattern. Walker (1930; see also Sterling 1998) reported some 24 *heiau* or ceremonial structures in Kaupō district, largely based on information provided by his Hawaiian informants in 1929. Most of these are smaller structures, and probably functioned as *heiau ho'oulu'ai*, temples for assuring the fertility of the land and production of crops. Two *heiau*, however, stand out for their massive size and labor invested in their construction: Lo'alo'a and Kou. As seen in Figure 4, these structures bracket the field system and Nāholokū fan, Lo'alo'a on the east and Kou on the west.

Lo'alo'a Heiau seems to have been situated on the edge of a dense part of the field system and overlooks Manawainui Stream. (The surrounding pasture has been extensively grubbed and only remnants of field system alignments can be detected on the aerial photos in this area.) This structure, one of the largest on Maui and indeed in the entire archipelago, is associated in Hawaiian traditions with King Kekaulike, who ruled Maui in the early 1700s (Abad 2000). Kolb (1991) carried out limited test excavations in Lo'alo'a as part of his study of Maui *heiau*, and obtained five  $^{14}\text{C}$  dates, which suggest that the earliest stages of construction date to c. A.D. 1440–1660. Lo'alo'a, like many large structures, has a complex construction sequence, and Kekaulike would have rebuilt and rededicated a previously existing structure in the early 1700s.

We mapped Lo'alo'a Heiau using both GPS and plane table and telescopic alidade in 2008, and the main structural outlines are shown in Figure 8. The temple consists of a massive, stone-filled elongated rectangular platform, nearly level with the ground surface on the west, but rising to a height of 6–7 m on the east, where four distinct terrace facings are present. The main platform is about 104 m long by 40 m wide, giving an area of roughly 4,160 m<sup>2</sup>.<sup>5</sup> We estimated that the platform incorporates approximately 10,400 m<sup>3</sup> of fill. The structure is clearly oriented to the NE, with the elaborated multi-faced terraces and well-paved court. The axis or orientation is 66°, which is significant, as this is the rising position of the star cluster Pleiades, called Makali'i in Hawaiian. The first appearance of Makali'i, around 17 November in the late eighteenth century, was carefully

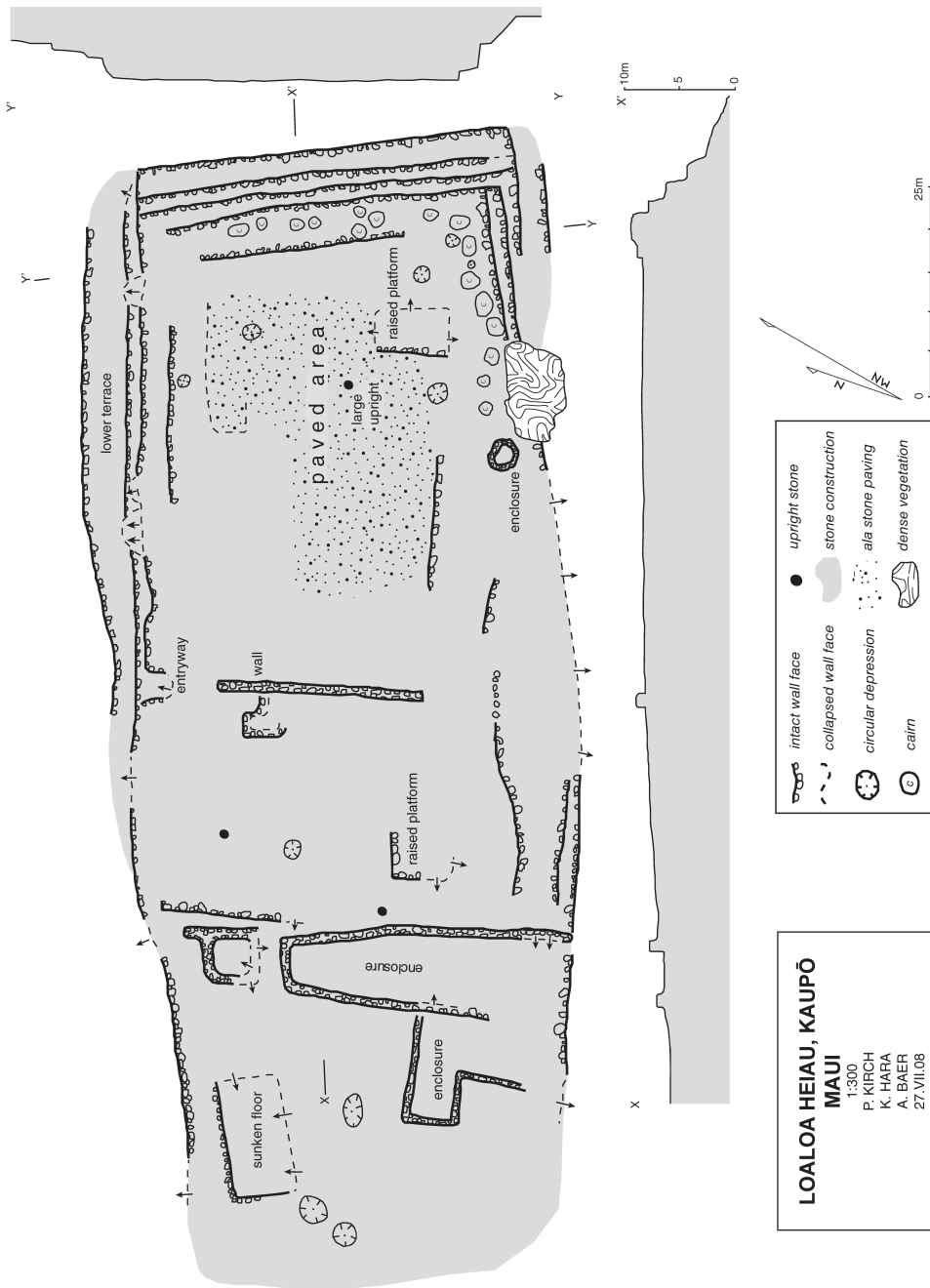


Fig. 8. Plan map of Lo'alo'a Heiau, based on plane table and alidade survey. Note that cross sections have a slight vertical exaggeration.

observed by the priests of the Lono cult, as this marked the beginning of the Makahiki season when the sweet potato crop would be harvested and tribute collections take place (Valeri 1985:194–199). Given Lo‘alo‘a’s location at the eastern edge of a vast dryland field season, this orientation is especially poignant, signifying the close association between the king, Lono, and the sweet potato fields that supported this staple-financed polity.

Kou Heiau, occupying a lava promontory jutting into the sea, brackets the western extent of the main Kaupō field system. The structure was reported by Walker (1930), who made a very inaccurate plan of it (Sterling 1998:180), but has not been studied or excavated since 1929. We made detailed GPS and plane table surveys of Kou Heiau in 2007 and 2008; Figure 9 is a version of our plane table map. The structure is quite different in morphology from Lo‘alo‘a, consisting of a large, elongated U-shaped enclosure defined by 3-m-high walls on the N and S, and a 3.6-m-high double-terraced E wall, which presumably was the main altar (Fig. 10). The main enclosure with its court open to the W is roughly 70 m long by 26 m wide. Based on measured cross sections through the enclosing walls, we estimated that the structure incorporates at least 1614 m<sup>3</sup> of stone fill.

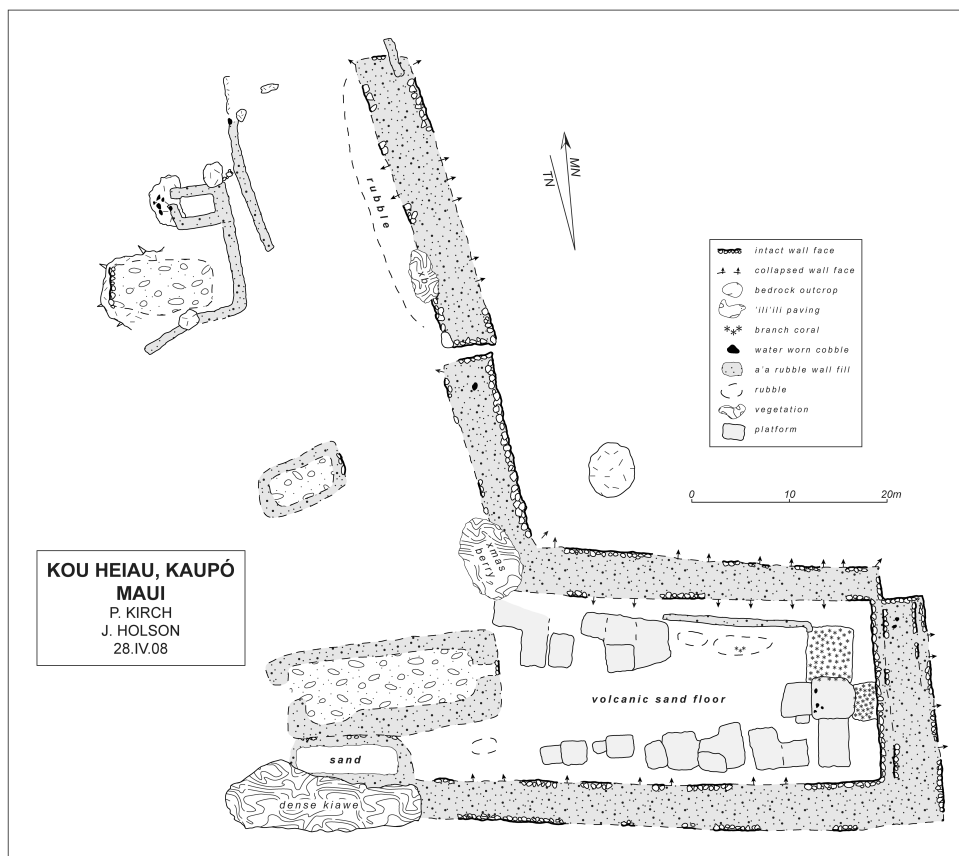


Fig. 9. Plan map of Kou Heiau, based on plane table and alidade survey.



Fig. 10. Interior face of the altar at Kou Heiau. J. Holson is standing next to a low platform covered in branch coral.

The orientation of Kou Heiau is also noteworthy. Unlike Lo‘alo‘a, it is not oriented to the NE, but rather has a main axis of  $104^\circ$ . This azimuth faces directly out to sea, and hence does not correspond with any visible geographic feature. However, an azimuth of  $104^\circ$  would correspond with the sunrise on 28 October in A.D. 1700.<sup>6</sup> There are a number of indications that the late pre-Contact Maui priests practiced solar observation, and this structure may well be oriented to mark the onset of the season of winter rains, which begin around the end of October. Given the importance of seasonal rainfall to the sweet potato crop in the Kaupō field system, such ritual marking of this important date in the horticultural calendar would not be surprising. The N wall of Kou Heiau may also have a significant orientation, as it does not depart from the main court at a right angle, but rather runs at an azimuth of  $357^\circ$ , aligned directly with the summit of Haleakalā Mountain. High mountain peaks were deemed to be the provenance of the war god Kū.

#### DISCUSSION AND CONCLUSIONS

Through a combination of GIS analysis of aerial photos and ground survey we have established that a major dryland field system formerly covered between 12.5 and 15 km<sup>2</sup> of the Nāholokū fan in the center of Kaupō District, Maui. This is the first such formal field system, marked by a classic reticulate grid of closely

spaced territorial boundaries and field divisions, to be identified for Maui Island, and adds archaeological support to Handy's (1940) ethnographic observation that the leeward slopes of Haleakalā, from Kaupō to Honua'ula, constituted one of the greatest dryland planting zones in the Hawaiian Islands.

Kaupō is associated in Hawaiian oral traditions with Kekaulike, a famous Maui king (*ali'i nui*) who on genealogical estimates is dated to approximately the early eighteenth century A.D. (Abad 2000). Fornander (1996:133) records that Kekaulike made Kaupō his residential seat, and assembled his army at Mokulau, preparing for a war of conquest against the rival Hawai'i Island polity. Kamakau (1961:66), a Hawaiian scholar of the mid-nineteenth century, says that Kekaulike built Kane-malo-hemo, probably a royal residential center, at Popo'iwi, as well as the war temples (*luakini*) of Lo'alo'a and Pu'u-maka'a at Kumunui and Poho'ula. After returning from his invasion of Kohala, Kekaulike resided at Kaupō, where he died of a violent illness (Kamakau 1961:69). The succession of the Maui kingship was then determined at Mokulau in Kaupō, and Kamehameha-nui was proclaimed the Maui paramount. These traditional accounts make it clear that Kaupō was a region of great importance in the late pre-contact Maui kingdom.

Kaupō apparently remained under the control of Kekaulike's descendants, for during the Great Mahele or division of lands between King Kamehameha III and the principal chiefs in 1848, at least 11 *ahupua'a* in Kaupō were claimed by the high chiefess Miriam Kekauonohi, the great-granddaughter of Kekaulike (Land Commission Award 11216, in Commissioner of Public Lands 1929:68–70; Barrère 1994:326–328). Also relinquishing and receiving lands in Kaupō during the Mahele was the chiefess Analea Keohokalole, great-granddaughter of Kame'eiamoku, a high chief of Kona district (Hawai'i Island) and counselor to Kamehameha I; she was the mother of King Kalākaua, who reigned in the later nineteenth century (Land Commission Award 8452, in Commissioner of Public Lands 1929:71–72; Barrère 1994:360–361). This intimate association between Kaupō and both the Maui and Hawai'i Island ruling lines is an indication of the traditional importance of these highly productive agricultural lands.

There are other hints in the ethnohistoric record of the importance of Kaupō and its agricultural field system. Of particular interest is Kamakau's account of the battle of Ka-lae-hohoa ("forehead beaten with clubs"), which took place in the sweet potato fields at Ka-puka-'auhuhu between the forces of the Maui king Kahekili and the invading Hawai'i Island king Kalani'ōpu'u. This battle, sometime between 1775–1779 and immediately prior to the arrival of Captain Cook off Maui in November 1778 (Kamakau 1961:84), speaks to the continued value of the region's productive and strategic capacity. The Maui warriors led by Kane'olaēlaē "concentrated the battle among the potato hills facing Ki'ei. The attack was led from below by Kane'olaēlaē through the furrows between the hills of [sweet] potatoes in direct line from Ka-lae-o-ka-'ilio." The famous Hawai'i Island warrior Ke-ku-hau-pi'o "stayed the flight of the [Hawai'i] army among the furrows of the potato patch until he got entangled in the vines," and was saved by the young warrior Kamehameha. As Kamakau observes, it was Kamehameha's prompt action in this battle in Kaupō's sweet potato fields that first brought him acclaim.

A narrow ethnohistoric window on Kaupō is provided by the account of Thomas K. Maunupau, a native Hawaiian who accompanied Bishop Museum eth-



nographer Kenneth P. Emory on an eleven-day research trip to Kaupō in May 1922 (Maunupau 1998). Maunupau published a serialized account of his experiences with Emory in the Hawaiian language newspaper *Ka Nupepa Koukua* in 1922–1923. Emory and Maunupau interviewed a number of older Hawaiians who were the last traditional sweet potato cultivators in Kaupō. On 9 May 1922, they sought out Poouwahi to obtain information on “canoe building and farming in former times” (Maunupau 1998:151). Maunupau reported that “Poouwahi said that the ancients had only small patches for their sweet potatoes. That was sufficient to supply the family and there never was a lack of food” (1998:152).

Maunupau’s brief summary of sweet potato planting in Kaupō, as gleaned from Poouwahi (1998:152–153), emphasizes the importance of ritual in the agricultural cycle. The work of clearing and planting a field was led by a ritual specialist (“the one who knew the prayers,” *ka mea i ike i ka pule*). A prayer for planting the first potato slips (which were themselves *kapu*) invokes male and female manifestations of the pig god Kamapua‘a, along with the deities Kū and Hina. Kamapua‘a is exhorted to “root and excrete” in the garden of the planters, and Poouwahi made it clear that the gnarled sweet potato tubers were compared to the “excrement of the pig.” Poouwahi told Emory and Maunupau that after planting the sweet potato patch was not weeded until the plants had matured. The ritual specialist again led the work of weeding, and carefully checked on the sacred first tubers to see if they were growing. A rite to free the field of *kapu* was then held, with a further prayer to the male and female pig gods. After this the patch was “left alone for six or seven months” while the crop matured. Maunupau closes his account by again emphasizing the high productivity of the Kaupō fields: “If one had a big family, a small patch was sufficient, there never was a lack of food” (Maunupau 1998:153).

Maunupau’s comments on the high productivity of the Kaupō sweet potato fields raise the question of how large a population might have been supported by this intensive field system. Some indication is given by available information on historical demography. The first missionary census to break down population by district, taken in 1831–1832 gave a total for Kaupō of 3220 persons, one of the highest figures for any Maui district (Schmitt 1973:18, Appendix A). This indicates a density of between 215 and 260 persons per km<sup>2</sup> of field system area. The 1831 census, however, came after more than five decades of depopulation due to introduced disease, to which the Hawaiians had little resistance. It would not be unreasonable to retrodict a pre-Contact population considerably higher than the 1831 census figure (Rallu 2007).

The potential production capacity of the Kaupō field system can alternatively be estimated based on ethnographically documented yields for sweet potato grown in traditional Oceanic horticultural regimes. Massal and Barrau (1973:25) report that “the average conditions prevailing in native gardens produce a yield ranging from 3 to 6 tons per acre” (6.7 to 13.5 metric tons per ha). Pospisil (1972:Table 24) gives yields ranging from 8.1 to 16.9 metric tons per ha for the Kapauku of New Guinea. If we use a figure of 10 metric tons/ha as a basis for calculating the total possible yield of the Kaupō system, depending on the actual total area cultivated (which we estimate at between 12.5 and 15 km<sup>2</sup>), an annual yield of between 12,500 and 15,000 metric tons of sweet potatoes might be possible at a high level of intensity (i.e., short fallow only between growing seasons).

The nutritional value of 100 g of sweet potato tuber is approximately 128 calories (Murai et al. 1958:104, Table 13), or 1280 kcal per metric ton. Thus the Kaupō system yield, as estimated, would be equivalent to between 16 and 19.2 million kcal. If on average the population of Kaupō was to consume 3 kcal of tubers per day (1095 kcal/yr), a population of between 14,611 and 17,534 persons might, in theory, have been supported. Of course, such calculations make no allowance for spoilage, for tubers fed to domestic animals such as pigs and dogs, or for fluctuations in harvest due to drought or other environmental perturbations, and are almost certainly higher than those that would have been achieved on a continuous basis. Such estimates, however, do suggest that a doubling of the 1831 census figure is not unreasonable, and indeed, a maximum population of up to 8000–10,000 persons for Kaupō strikes us as not unreasonable.

Ultimately, estimating the population of Kaupō must depend on other kinds of data, such as archaeological house counts, and the calculations given above are useful only as order-of-magnitude estimates of the potential productive capacity of the district's dryland field system. Nonetheless, it is clear that Kaupō with its field system at one time played an important role in the emerging Maui polity, particularly in the final century prior to European contact, when it became the seat of the paramount Kekaulike. It was the enormous capacity of these field systems that enabled the rise of complex societies based on an economic system of staple finance. The monumental temples of Lo'alo'a and Kou, which flank the Kaupō fields, are an enduring reminder of the inseparable links between agriculture and the emergent archaic states of ancient Hawai'i.

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#### ENDNOTES

1. A fourth major field system is known to have existed in Ka'u District, and parts of it can be discerned on aerial photographs, but it has yet to be archaeologically defined.
2. Aerial photos for this region have recently been retaken at a lower resolution for use in public forums including Google Earth. While these provide a valuable resource for quick examinations of the area, the lower level of resolution does not allow for the more fine-grained archaeological analysis.
3. Local informants have told us that Kaupō Ranch undertook considerable land grubbing during the 1960s, for the purpose of pasture improvement.
4. The name Paukū appears on old maps for this area (see also Sterling 1998:166) and we believe that it is the proper section name for this land. However, modern residents of Kaupō refer to the area as Kokowai.
5. Kolb (1991:173) gives the surface area as 5115 m<sup>2</sup>, but we believe our GPS-based measurement to be more accurate.

6. As calculated by the computer program TheSky, version 5, the sunrise on 28 October 1700 occurred at 7:25 A.M. at an azimuth of 104°18'54".

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## ABSTRACT

The late pre-contact political economies of Hawai'i and Maui Islands were supported in large part by intensified dryland field systems, focused on the cultivation of sweet potatoes. Three such systems have been well documented for Hawai'i Island, and one for Moloka'i Island, but none previously for Maui. We report here the results of remote sensing and GIS analysis, combined with ground survey, of such an intensive field system in Kaupō District, Maui. The field system is archaeologically manifested by a closely spaced grid of east-west trending embankments, delineating small field plots, bisected at right angles by longer north-south trending walls, which primarily appear to be territorial divisions. A range of smaller features such as enclosures, shelters, and platforms are found within the field system area indicating the presence of a complex social community integrated within the system. In aggregate the field system covered between 12.5 and 15 km<sup>2</sup>, and could readily have supported a population of 8000–10,000 persons. Hawaiian oral traditions indicate that Maui king Kekaulike made Kaupō his seat in the early eighteenth century. Two large temples, Lo'alo'a and Kou, are situated at the east and west extremes of the field system, and further indicate the significance of this highly productive landscape. **KEYWORDS:** Polynesia, Hawai'i, agriculture, landscapes, population, environment, temples.